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research article

Assessing the value of price caps and floors

CÉDRIC PHILIBERT*

Renewable Energy Division, International Energy Agency, 9 rue de la Fédération, 75015 Paris, France

This article assesses the long-term economic and climatic effects of introducing price caps and price floors in hypothetical global climate change mitigation policy. Based on emission trends, abatement costs and equilibrium climate sensitivity from IPCC and IEA reports, this quantitative analysis confirms that price caps could significantly reduce economic uncertainty. This uncertainty stems primarily from unpredictable economic growth and energy prices, and ultimately unabated emission trends. In addition, the development of abatement technologies is uncertain. Furthermore, this analysis shows that rigid targets may entail greater economic risks with little or no comparative advantage for the climate. More ambitious emission objectives, combined with price caps and price floors, could still entail significantly lower expected costs while driving similar, or even slightly better, climatic outcomes in probabilistic terms.

Keywords: climate change; economic uncertainty; emission allowances; GHG emissions; mitigation policy; price caps; price floors

Cet article évalue les effets économiques et climatiques à long-terme de l'introduction de prix plafonds et prix planchers dans une politique mondiale hypothétique de lutte contre le changement climatique. Basée sur les tendances d'émissions, les coûts de réduction des émissions et la sensibilité climatique à l'équilibre tirés des rapports du GIEC et de l'AIE, cette analyse quantitative confirme que les prix plafonds pourraient réduire considérablement l'incertitude économique. Cette incertitude résulte principalement de l'imprévisibilité de la croissance économique et des prix des énergies, et finalement des trajectoires d'émissions spontanées. Par ailleurs, le développement des technologies de contrôle des émissions est incertain. Plus encore, cette analyse montre que des objectifs rigides pourraient présenter des risques économiques plus élevés pour un avantage comparatif minimal ou nul pour le climat. Des objectifs d'émissions plus ambitieux, liés à des prix plafonds et des prix planchers, pourraient toujours entraîner une réduction significative des coûts attendus tout en obtenant des résultats semblables ou même légèrement meilleurs pour le climat en termes probabilistes.

Mots clés: changement climatique; émissions de GES; incertitude économique; politique de réduction des émissions; prix plafonds; prix planchers; quotas d'émissions

1. Introduction

The climate change issue is plagued with many uncertainties. Future unabated emissions trends depend on uncertain future economic growth, energy intensity, and carbon intensity of the energy mix, which itself depends on fuel availability and prices. The Earth's climate sensitivity is also largely uncertain. Uncertainties should not delay action in mitigating greenhouse gas emissions, but make the task of setting policy objectives rather challenging. A full cost–benefit analysis might not be possible. Nevertheless, abatement costs matter, as do environmental benefits.

Price caps and price floors, which also appear in the literature as 'price corridors', 'price collars' (Fell and Morgenstern, 2009) or 'symmetric safety valves' (Burtraw et al., 2009), have been suggested

E-mail: cedric.philibert@iea.org

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as possible complements to quantitative emission limits and emissions trading to create a more flexible response to the threat of climate change in the context of uncertain costs. Under a price cap, emissions beyond the quantitative targets or cap would take place, but emitters – firms or households at the domestic level, countries at the international level – would need to buy additional allowances at a set price. While cap-and-trade would make the objective cost-effective, if the costs were nevertheless to exceed some preset threshold, emissions beyond the targets would be possible but would be heavily taxed. Meanwhile, price floors would 'kick in' if costs were much lower than expected. Price floors would help maintain, in probabilistic terms, the emission outcomes of mitigation policies, and would have long-lasting effects on abatement costs through technology development.

Economic theory suggests that, when abatement costs are uncertain, price caps reduce expected costs and reduce cost uncertainty. However, the uncertainty would be shifted on the side of emissions. How bad would this be? Possibly less than it may at first seem. Price caps make it possible to set more ambitious policies for the same, or lower, total expected costs (Philibert and Pershing, 2002). Meanwhile, price floors may help improve the environmental outcome when costs end up lower than expected. Targets, price caps and price floors might thus possibly be arranged to lead to similar or even better climate results, in probabilistic terms, than rigid targets, while still reducing expected costs. Investigating this intriguing possibility is the focus of this article.

To assess the possible value of price caps and floors in the future global climate mitigation architecture, a simple model of greenhouse gas mitigation costs, CO_2 concentrations and temperature changes was developed, building on the IEA's *Energy Technology Perspectives* (ETP-2008) and the IPCC's *Fourth Assessment Report* (AR4) – resulting in the ACTC (Abatement Costs Temperature Changes) model.

The hypothetical mid-term objectives considered were halving global energy-related CO_2 emissions by 2050, as proposed by the G8 leaders at their meeting in Toyako (Japan) in July 2008. Thousands of so-called Monte Carlo simulations, where uncertain parameters take random values, were performed; and the total discounted expected abatement costs, decadal emissions, CO_2 concentrations, and finally committed temperature changes were computed in various cases; from 'no policy' to rigid targets to various combinations of targets with price caps and floors. Section 2 provides more information on the model and the methodology used; Section 3 first presents the model outputs in the absence of climate policy, thus setting the scene, and goes on to consider 'straight' or 'rigid' targets with certain results, defining intermediate targets on the basis of best-guess values, then assessing the implications of uncertainties on marginal and total abatement costs. Section 4 assesses the effects of price caps and price floors and the possible tightening of targets that they might facilitate. Section 5 concludes with a discussion of the results, pointing out some caveats and considering directions for future research.

2. Methodology

This research uses an extended version of a model of the costs of climate mitigation policies, the ACTC model (for full details, see the Appendix in Philibert, 2008), which is relatively easy to reproduce (Golub, 2009). Its description here is limited to what seems necessary for understanding the results.

2.1. The ACTC model

The ACTC model is a highly aggregated model of the global economy, with no distinction between countries or sectors. It projects the growth rate of the economy and future global unabated energy-related CO_2 emissions: the business-as-usual (BaU) scenario. The range of uncertainty embraces most of the uncertainty described in the *Fourth Assessment Report* (AR4) of the Intergovernmental Panel on Climate Change (IPCC, 2007). A subjective probability function is introduced, with a 'best-guess' that corresponds to the projection in ETP-2008 (see Figure 1). For simplicity, the model is based on decadal periods.

The ACTC model includes an abatement cost function for the period 2041–2050 mimicking the abatement cost curve based on the results reported in ETP-2008 (IEA, 2008) with its uncertainty range (see Figure 2). To reflect technical progress and abatement cost reduction over time, abatement cost functions for earlier periods were adjusted to fit the information on abatement potentials in IPCC AR4. Emission reductions forced in one decade last forever in the model, i.e. they durably modify the BaU emission levels in subsequent decades.

The ACTC model allows the costs of quantitative emissions objectives to be studied at a global level that can be either 'certain' ('rigid'), or 'flexible' (if there are price caps and floors). It includes an assessment of CO_2 concentration levels and resulting temperature changes, but makes no attempt to monetize policy benefits. The ACTC model takes directly from the IPCC AR4 the simple assumption that 60% of the emitted CO_2 remains in the atmosphere, and computes the resulting long-term equilibrium temperature change over pre-industrial levels with a fitted approximation of its probability density function (see Figure 3), as appears in IPCC AR4. To make things perfectly clear – the ACTC model does not pretend to be a climate model. Its input is made up of the results of many climate models, consolidated by the IPCC.

To take full account of uncertainties, thousands of Monte Carlo simulations were run, in order to test the many combinations of the uncertain values that the most important parameters may take. This method is necessary because the introduction of price caps and floors truncates cost curves in such a way that the climatic outcomes cannot easily be evaluated algebraically.

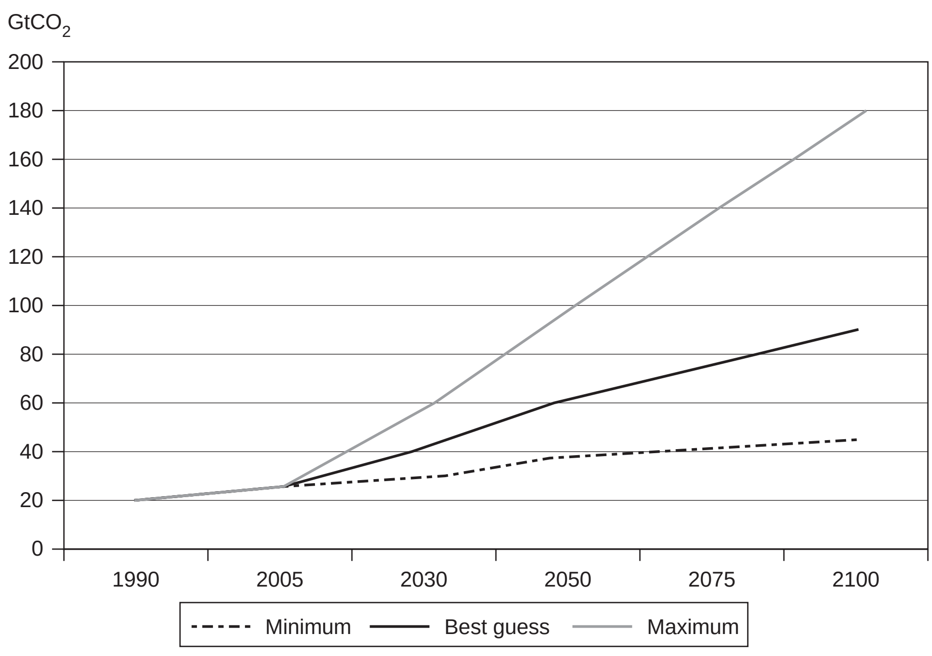

FIGURE 1 Business-as-usual (BaU) global energy-related CO_2 emissions in the ACTC model

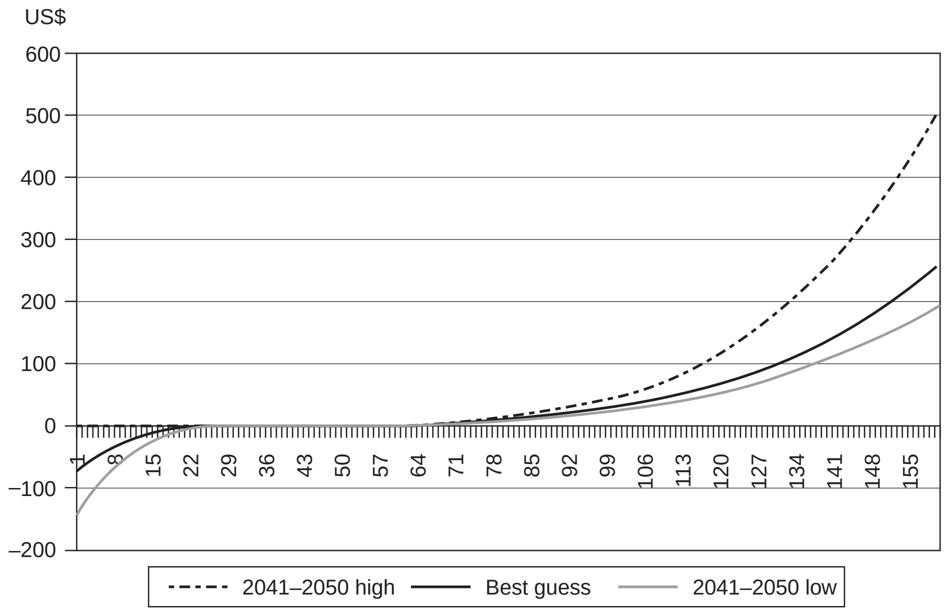

FIGURE 2 Marginal abatement cost (MAC) in the ACTC model for the period 2041–2050

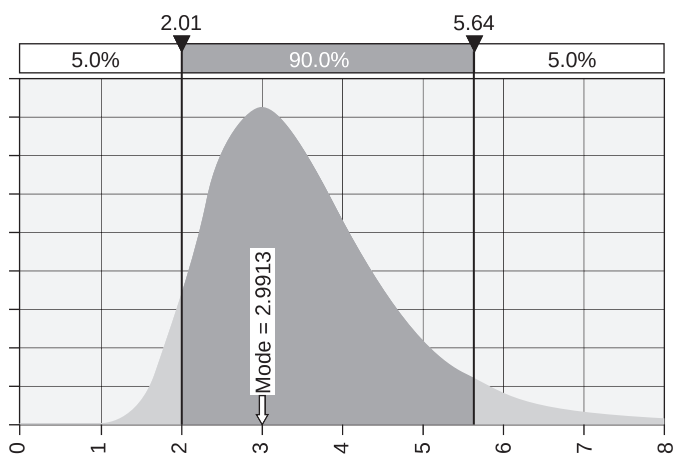

FIGURE 3 Climate sensitivity in the ACTC model (in degrees Celsius)

2.2. Halving global energy-related emissions by 2050

The IPCC AR4 considers emission reductions to 50–85% below 2000 levels, to be compatible with stabilized CO_2 concentrations of 350–400 ppm, or all GHG concentrations (in CO_2-eq) of 445–490 ppm, and a global mean temperature increase of 2°C–2.4°C above pre-industrial temperatures at equilibrium using 'best-estimate' climate sensitivity.

The G8 leaders, at their meeting at Toyako (Japan) in July 2008, declared that they

> seek to share with all Parties to the UNFCCC the vision of, and together with them to consider and adopt in the UNFCCC negotiations, the goal of achieving at least 50% reduction of global emissions by 2050 (G8 Leaders, 2008).

The analysis focuses on at least halving global emissions by 2050, and investigates whether some lower emission levels could be achieved for similar expected costs if price caps and floors were introduced into the global architecture.

Philibert (2008) suggests that the main criterion to assess policies is the 'warming committed by 2050' – i.e. the long-term equilibrium warming that would result from a stabilization of CO_2 concentrations at the level reached by 2050. This concept is, of course, different from 'transient warming' – i.e. the warming actually realized at that date – due to the thermal inertia of the oceans and land masses.

In this article, however, the main criterion used is the warming committed by 2100. The ACTC model was extended to 2100 with respect to the analysis of CO_2 concentration and climate outcomes. Thus, except for the 'No policy' case, all the results presented in this article rest on a similar additional assumption that the remaining emissions are progressively eliminated between 2050 and 2100. This extension provides a clearer picture of the climate outcomes of the various climate policies considered, on a time horizon that corresponds to achieving atmospheric CO_2 stabilization. However, given the lack of robust information with respect to abatement costs beyond 2050, this progressive elimination is not accounted for in the cost assessments, which are therefore limited to the period 2011–2050.

2.3. Differences from earlier studies

Previous research has attempted to assess the introduction of price caps in global mitigation architectures/domestic emissions trading schemes. In particular, Pizer (2002), building on Weitzman (1974), showed that in the case of climate change, introducing price caps reduces expected costs to a much greater degree than it reduces expected benefits; as a result, expected net benefits (welfare gains) would be five times greater with flexible targets (or carbon taxes) than with rigid targets.

Pizer (2003) further explored the conditions under which rigid quantitative targets might still be preferred. He showed that severe catastrophic climate damage triggered by known GHG concentration thresholds may indeed call for purely quantitative targets.

There are two main differences between the present study and Pizer's. Spelling out these differences may help to achieve a clearer understanding of the aims of this study. They are as follows:

- Pizer considered the difficulty of choosing a discount rate as a major source of uncertainty, which explains about half the increase in expected net benefits of climate policy due to price caps. The ACTC model uses a 5% discount rate, thereby focusing on other sources of uncertainty.
- Pizer offered views on the optimal level of abatement and looked for the optimal setting of targets and price caps, or taxes. This study takes the aim of halving emissions by 2050 for granted, and only questions whether such an objective must be reached with a great level of precision and certainty despite uncertain abatement costs, or not. This aim corresponds with an expected amount of expense that the international community may find acceptable to spend to mitigate climate change risks: our study seeks the most cost-effective use of that money.

There are two possible rationales for setting more ambitious targets after price caps are introduced: (1) if the objective is to maintain optimality in setting targets, one should introduce price floors if price caps have been included. If price floors are deemed politically or financially difficult to introduce, their absence must be compensated for by some tightening of the original targets (Cournède and Gastaldo, 2002). (2) If the uncertainty about marginal benefit is too 'deep', and there is no real best guess (Schneider, 2003), the idea is to maximize the environmental benefits for the same anticipated costs. Even if price floors are introduced, tightening the original targets still makes sense. A first step is to search for the target that provides the same expected climatic results with caps and floors – and lower expected costs. A second step is to look for the target that entails the same expected costs, but with better climate outcomes (Philibert, 2006).

3. 'No policy' case and rigid targets

In this section we briefly assess the climate outcomes that would result from the absence of any policy to mitigate climate change, and the costs and climate consequences of setting and achieving the rigid target of halving global emissions by 2050.

3.1. 'No policy' case

In the absence of policy, global energy-related CO_2 emissions would continue to grow, reaching, under best guess, 42 Gt CO_2 by 2030, 60 Gt CO_2 by 2050, and 90 Gt CO_2 by 2100. This would lead to CO_2 concentrations of 534 parts per million (ppm) by 2050 and 820 ppm by 2100 under best-guess estimates.

Running 3,000 Monte Carlo simulations with the ACTC model shows CO_2 concentrations in the range of 662–1,067 ppm by 2100. Figure 4 represents the probability distribution of the temperature change committed by 2100 in the 'No policy' case (temperature changes in degrees Celsius are in abscissa; the taller the bar the greater the probability). There is virtually no chance that the warming does not exceed 2°C, and less than a 20% chance that it does not exceed 4°C. There is a 50% risk that the warming exceeds 5.25°C (median value). There is an 18.8% risk that the warming exceeds 7°C: the 'No policy' scenario therefore looks like a 'No future' scenario. Undertaking no policy is not an option.

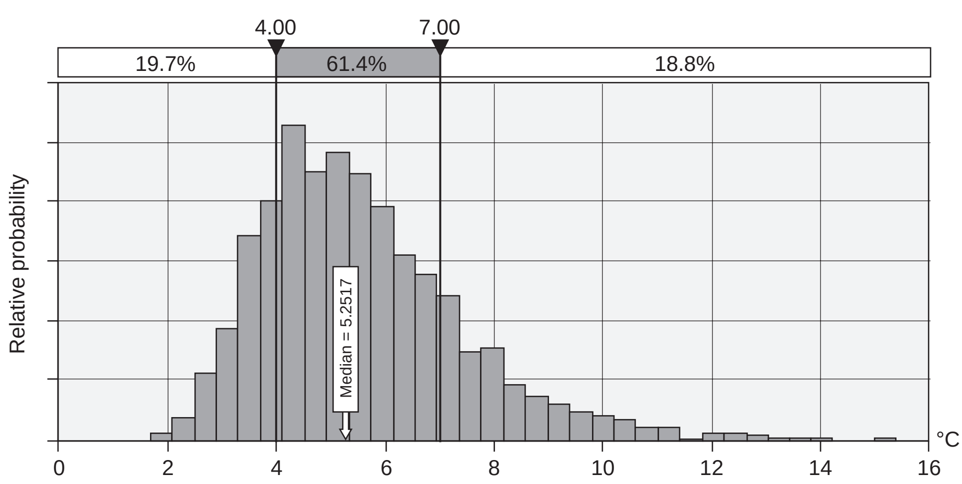

FIGURE 4 Warming committed by 2100 in the 'No policy' case

3.2. Setting intermediate targets

On the basis of the G8 final communiqué in Toyako (G8 Leaders, 2008), we want to halve global energy-related CO_2 emissions by 2050. The communiqué did not specify any reference level, so we assume it could be close to the level of emissions known at the time, and we take as reference the 2005 level. We factor a target of 135.68 Gt CO_2 for 2050 or, more precisely, for the period 2041–2050. From this important mid-point, we proceed backward to establish a full set of decadal targets to stabilization by 2010. That is, the model is run to find the intermediate target values (2011–2020, 2021–2030, and 2031–2040) that minimize the net present value of overall abatement costs until 2050. We first ignore the uncertainty, i.e. we use only best-guess values.

Table 1 shows the allowed emissions, percentage of reference levels, marginal abatement costs (MAC) and total abatement costs (TAC) for the optimal pathways towards 2050 levels for the target studied. According to such pathways global emissions would optimally peak at some point between 2011 and 2020. This is in line with IPCC (2007).

TABLE 1 Intermediate objectives for halving emissions by 2050 from 2005 levels

	2011–2020	2021–2030	2031–2040	2041–2050	Total (NPV)[a]
Reference 2005	94%	83.5%	74.5%	50%	
Cap (Gt CO_2)	257.835	234.156	206.237	135.680	833.9
MAC (\$/t CO_2)[b]	67	101	158	252	
TAC (bn \$)[c]	350	1,119	3,002	6,575	2,754

[a] NPV = Net present value.
[b] MAC = Marginal abatement costs.
[c] TAC = Total abatement costs.

3.3. Halving global emissions from 2005 levels: straight targets

Let us now run again 3,000 Monte Carlo simulations. GDP growth rate per decade and carbon intensity, and also coefficients driving the MAC curve, take random values. No price cap is factored in yet. We then look at the cost outcomes – MAC, TAC during the first period 2021–2020, net present value of total abatement costs to 2050 in absolute terms and in percentage of GDP – when halving global emissions by 2050 from both 2005 levels and 1990 levels.

Figure 5 shows the net present value of total abatement costs until 2050. This has a mean value of US\$7,885 billion, against a best-guess value of US\$2,754 billion. The expected value when uncertainty is taken into account is thus basically three times larger than when it is not. This, of course, is a very important result in itself, which results from the steep slopes of the marginal abatement cost curves and the breadth of the uncertainty, particularly with respect to BaU emissions. The savings when BaU emissions are less than expected are much smaller than the additional costs incurred when BaU emissions are more than expected.

It is also interesting to consider total abatement costs in percentage of the world gross product (WGP). The mean value is 0.39%, and the considerable dispersion extends from –0.019% to +5.47%.

A closer look at the first period 2011–2020 reveals that MAC have a mean or average value of US\$92, which is roughly 40% higher than the best-guess value of US\$67. This stems from the steepness of the MAC function: higher-than-expected unabated emissions increase MAC much more than lower-than-expected unabated emissions reduce MAC.

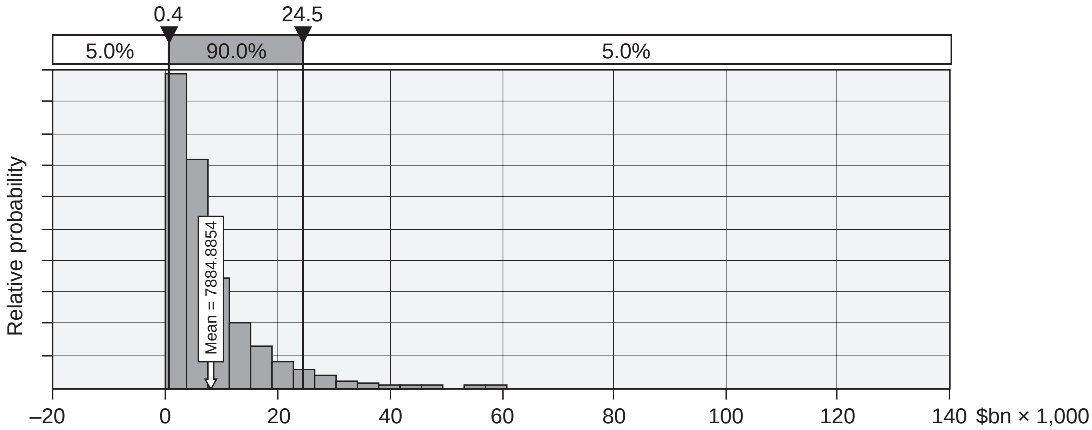

FIGURE 5 Net present value (NPV) of abatement costs to 2050 (no price cap)

Note: Mean value is in $bn

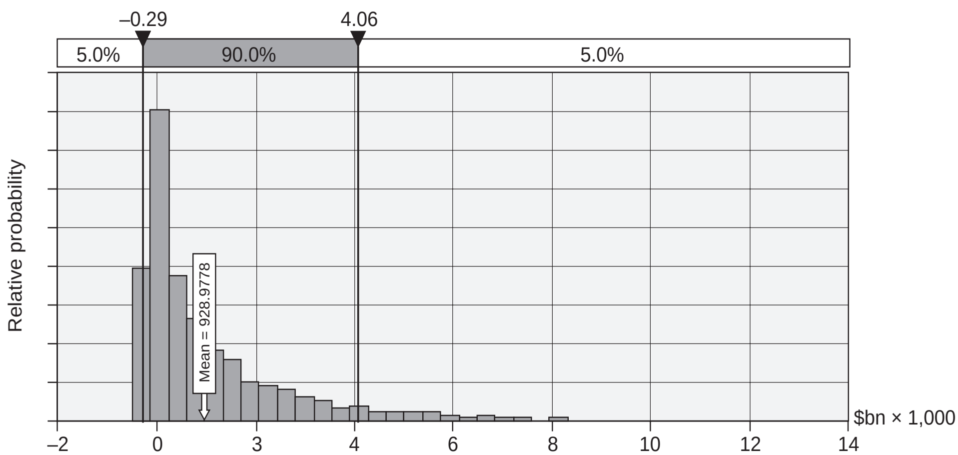

FIGURE 6 Total abatement costs in the period 2011–2020 (no price cap)

Note: Mean value is in $bn

Uncertainties have a more dramatic effect when TAC for the same 2011–2020 period are computed, as apparent in Figure 6. The mean value is US$929 billion – whereas it was only US$350 billion under best-guess values for all parameters. Total costs are computed as an integral of the marginal cost function, and thus grow faster than marginal costs when the required abatement augments. Table 2 summarizes the expected MAC, TAC, and TAC in proportion to the GDP during the periods following to 2050, by comparison with the best-guess values, while halving global emissions from 2005 levels. It is worth noting that, although mean values are several times higher than best-guess values, the percentage of total expected costs does not exceed (on average) 1% of expected GDP in any period – a result that is consistent with the Stern Report (2006).

Let us now consider the environmental results of this policy to 2100. As emissions over this century are known with quasi-certainty[1], the CO_2 concentration reached by 2050 is known to be 484 ppm or very close to 484 ppm. The results for temperature change, however, reflect the uncertainty that affects the equilibrium temperature change in the IPCC AR4 (Figure 7). When compared with

TABLE 2 Marginal and total abatement costs to 2050 of halving CO_2 from 2005 levels

		2011–2020	2021–2030	2031–2040	2041–2050	Total (NPV)[a]
MAC ($/t)[b]	Best guess	67	101	158	252	
	Mean	92	181	288	504	
TAC (bn$)[c]	Best guess	350	1,119	3,002	6,575	2,754
	Mean	929	3,729	8,307	18,179	7,885
TAC in % WGP[d]	Best guess	0.04%	0.10%	0.20%	0.33%	
	Mean	0.11%	0.30%	0.50%	0.80%	0.39%

[a] NPV = Net present value.
[b] MAC = Marginal abatement costs.
[c] TAC = Total abatement costs.
[d] WGP = World gross product.

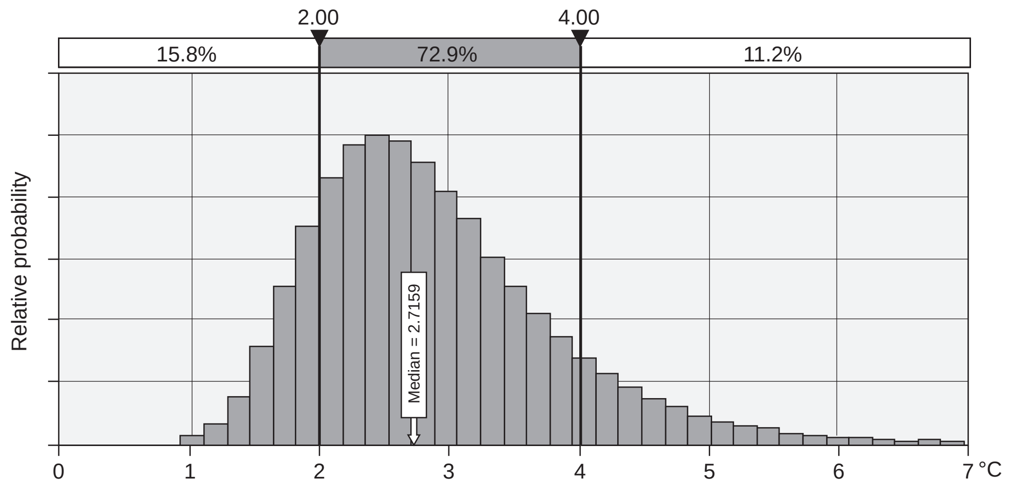

FIGURE 7 Warming committed by 2100, rigid targets of half 2005 levels

the 'No policy' case, these results are important. The median value of warming committed by 2100 is down from 5.25°C to 2.72°C. The chance of not exceeding 2°C is now 15.8%, and the risk of exceeding 4°C is down from 80.3% to 11.2%. The risk of exceeding 7°C has been virtually eliminated.

4. Assessing price caps and price floors

In this section we introduce price caps during the four periods to 2050, testing various levels, to find out the likely effects on both abatement costs and actual emissions. We tighten the targets, and introduce price floors with the same purpose. We then seek the combination of targets, price caps and floors that would lead to similar environmental results – starting with the same average concentration levels. Then we search for the combination that would entail the same expected costs, presumably with better environmental results.

Price caps could be simple compliance payments to governments (for domestic sources) and/or to some international entity (for governments) at the end of commitment periods – at prices set up and known by all at their outset. Price floors could be reserve prices in periodic auctioning, thus creating no liability for government (no need for subsidies).

4.1. 'Low' price caps

Let us test two different price cap schedules. We name the first, 'low price caps', as they are deliberately set about one-third below MAC in each period. The second, 'high price caps', is set about 50% higher than the MAC in each period.

We define 'low' price caps at US$40, 60, 80 and 100, respectively, in the four periods and run the model 3,000 times. Total expected abatement costs during the first period are considerably reduced – indeed they become negative, at –US$34 billion, as energy savings (negative to no cost options) are more important than positive costs of other emissions reductions.

However, emissions during the first period 2011–2020 are on average about 12 Gt CO_2 higher than the 257.835 Gt CO_2 target, and in about 10% of the cases, are 30 Gt CO_2 above the target, as shown in Figure 8 (the highest bar shows the probability of achieving the target, while the lower bars to the right show the frequency of outcomes when the price caps 'kick in').

The deviation from the desired emission trajectory increases over time and, in the last period, 2041–2050, emissions are considerably above the target (136 Gt CO_2 in 10 years) at 222 Gt CO_2 on average – a 63% increase – and twice as high in about 20% of the cases.

Over the entire period 2011–2050, the net present value of total expected abatement costs is down to US$645 billion, a sharp reduction from the case with straight targets. The nature of this reduction in expected costs is further discussed in Section 4.3.

CO_2 concentrations range from 482 to 544 ppm by 2100. If the most likely outcome is 482 ppm, the mean value is 498 ppm – against 484 ppm in the previous case. This relatively modest difference illustrates the cumulative nature of the climate change issue: deviations of 63% in emissions (2041–2050) end up with a 3% increase in concentrations. The warming committed by 2100 has a median value of 2.85°C (Figure 9). There is a 12.5% chance of not exceeding 2°C, and a 14.8% risk of exceeding 4°C.

These results are considerably more favourable to the environment than the 'No policy' case. They reveal, however, some degradation of environmental outcomes when compared with rigid

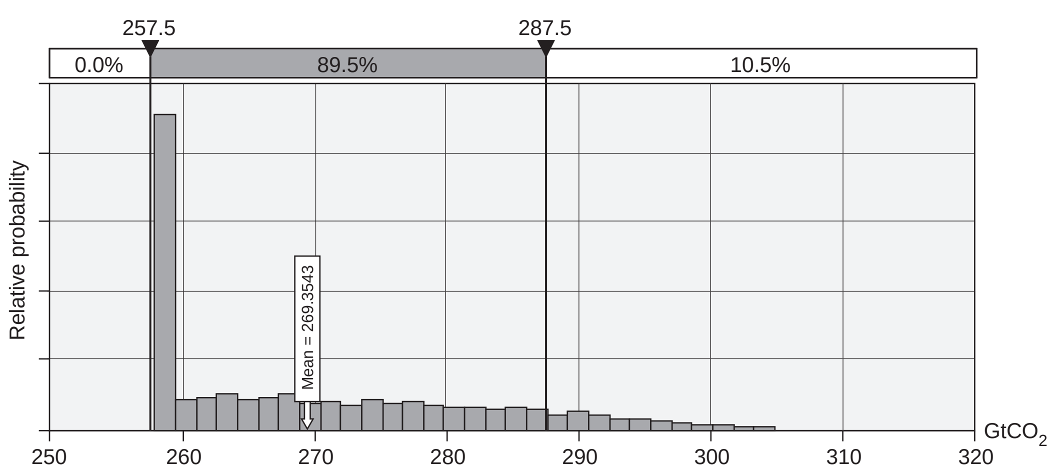

FIGURE 8 Actual emissions 2011–2020 with US$40 price cap

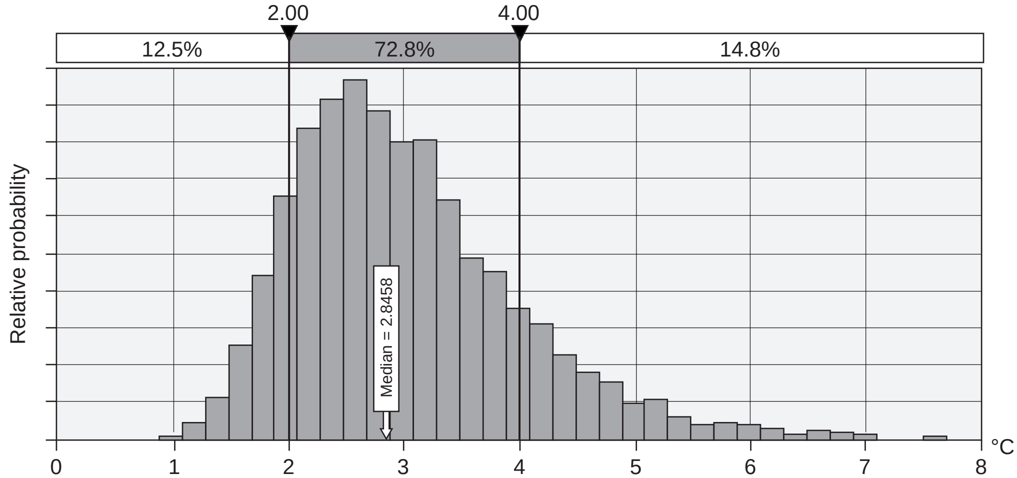

FIGURE 9 Warming committed by 2100 with 'low' price caps

targets. 'Low-level' price caps do reduce expected costs and the cost uncertainty of climate policy, but weaken its environmental results, though perhaps less than expected. It must be emphasized, however, that these 'low-level' price caps remain relatively consistent with the ambition of the targets. If price cap levels were set at significantly lower levels, they would probably drive much more substantial deviations of the climatic outcomes.

4.2. 'High' price caps

We set price caps at high levels – US$110, 150, 230 and 350, respectively – for each period. Expected costs during the first period reach US$428 billion – about half their initial level. Emissions during that period remain higher than the target at 261 Gt CO_2. Emissions during the 2041–2050 period have a mean value of 164 Gt CO_2, which is about 20% above the target (Figure 10). Even relatively high price caps create a significant deviation from the desired objectives.

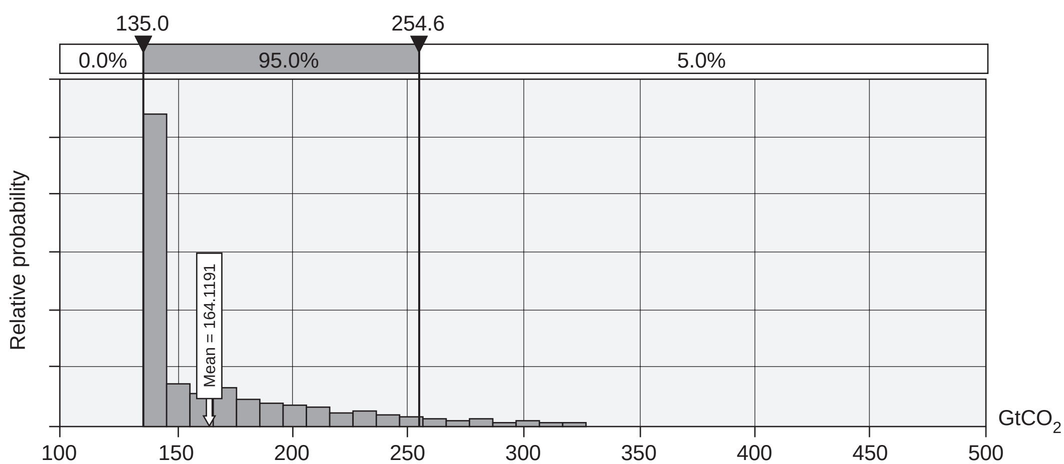

FIGURE 10 Actual emissions 2041–2050 with 'high' price caps

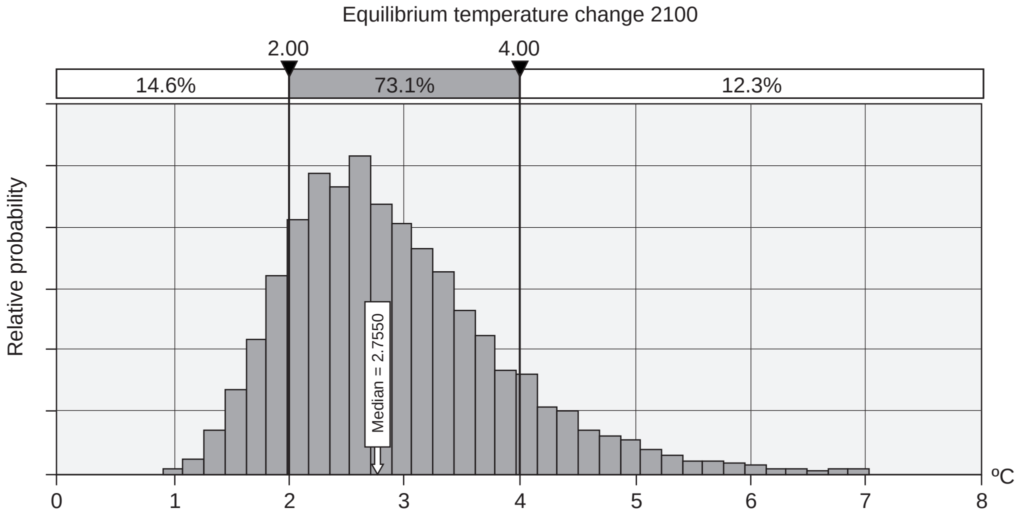

FIGURE 11 Warming committed by 2100 with 'high' price caps

Over the entire period 2011–2050, total expected costs have a net present value of US$2,925 billion. CO_2 concentrations by 2100 are in the range 481–531 ppm, with a mean value of 489 ppm. Temperature change has a median value of 2.76°C, as can be seen from Figure 11, which is still above the result with a rigid target, though the difference has narrowed.

4.3. Price caps and price floors

Let us now consider combining 'middle–high' price caps (somewhat above the best-guess marginal abatement costs in each period) and price floors (somewhat below the same costs). We set price caps at US$80, 120, 180 and 260 for the periods 2011–2020, 2021–2030, 2031–2040 and 2041–2050, respectively, and price floors at half these levels, i.e. US$40, 60, 90 and 130.

Emissions during the first period have a mean value of 260.1 Gt CO_2, which is only 1% above the 257.835 Gt CO_2 target. The deviation is much smaller with price floors than without them. In about 24% of the cases, the target is exceeded by 1 Gt CO_2 per year or more, while in about 13.4% of the cases emissions are 1 Gt CO_2 per year below the target (Figure 12). Abatement costs are down to US$297 billion – one-third of their initial value.

Emissions during the last decade before 2050 have a mean value of 160.5 Gt CO_2; still higher than the 135.68 Gt CO_2 target, which is reached or exceeded in 43.7% of the cases. The price floor even makes it possible that emissions come down to zero, though the probability is low and requires the combination of an extremely low BaU trend with the lowest possible MAC. There is a 5.7% risk, however, that emissions are twice as much, or more, than the target (Figure 13).

Over the entire period to 2050, the net present value (NPV) of total expected abatement costs is US$2,292 billion. This interesting result shows the usefulness of price floors. In comparison with high price caps, total costs are reduced by 21.6% (US$2,292 billion vs. US$2,925 billion). Still, concentration results are slightly better by 2100, in the range 441–528 ppm, with a mean value of 488 ppm.

Probably no less important from a political standpoint is the sharp reduction in cost uncertainty – not only expected costs. When expressed in percentage of the world gross product, the range of likely costs of mitigating climate change, which with rigid targets extended from 0 to 5.5%, has narrowed from 0 to 0.2%.

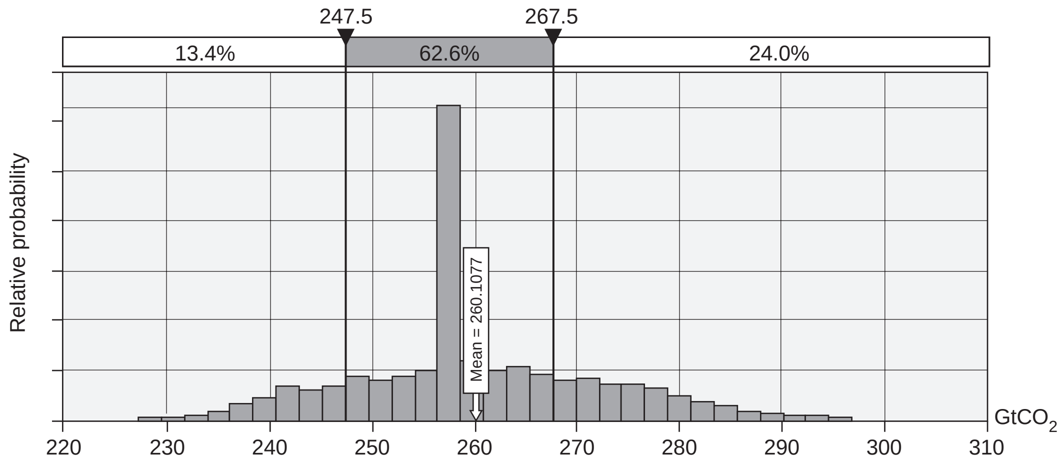

FIGURE 12 Actual emissions 2011–2020 with US$80 price cap and US$40 price floor

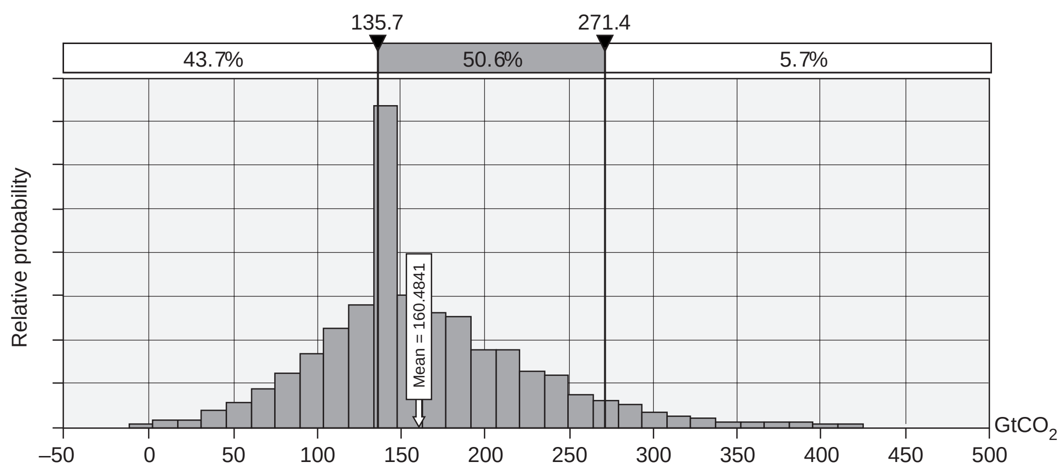

FIGURE 13 Actual 2041–2050 emissions with price caps and price floors

Results expressed in temperature changes are worth considering (Figure 14), as they are fairly close to those obtained with rigid targets, though not exactly the same, with a median temperature change of 2.75°C vs. 2.72°C with rigid targets.

The results warrant closer examination. A reduction in expected costs to one-third, and a narrowing of the uncertainty range by one order of magnitude while keeping the climatic results almost the same, may seem 'too good to be true', and needs some explanation. Price caps do not reduce the actual costs – when the uncertainty is resolved. However, they do reduce the expected costs, which have been computed taking the uncertainties into account – the only costs that the rational decision-makers should consider.

As seen above, the expected costs are about three times greater than the 'best-guess' abatement costs calculated when one selects the best-guess value for each parameter. The steepness of the marginal cost curve – a cost that increases rapidly with the amount of abatement required to

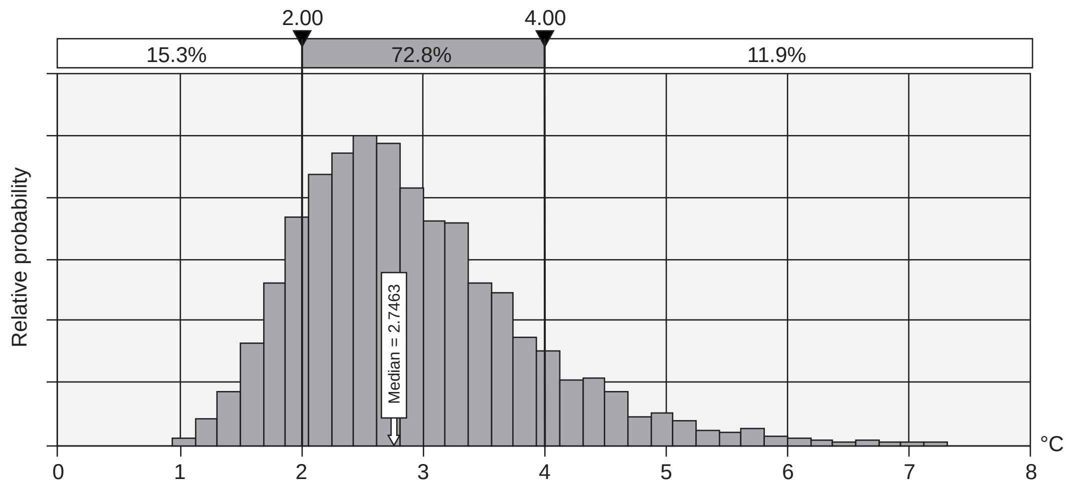

FIGURE 14 Warming committed by 2100 with price caps and price floors

achieve the fixed target – combines with the breadth of the uncertainties, notably those relative to economic growth and BaU emissions, to explain this result. When price caps are introduced at levels close to those of the marginal abatement costs in each decadal period, they somehow bring the expected costs close to the best-guess costs – three times smaller.

Meanwhile, the price floor reduces emissions beyond the quantitative targets when costs are small. They increase the costs attached to a given target but, as they help maintain a symmetry of the possible emission outcomes around the target, they do reduce the expected costs of achieving (in probabilistic terms) given emission, concentration, and finally temperature change outcomes.

These results, however, are dependent on the assumptions of the model. To replicate the marginal cost curve of ETP-2008, numerical functions were introduced to compute the MAC as a function of the amount of abatement in each decade. After some point these costs grow rapidly, and continue to grow when the amount of the required abatement exceeds what is considered in ETP-2008, which had only one scenario for BaU emissions. Indeed there is little information either to validate or invalidate the choice of not introducing another 'kink' in that curve, which could reflect, for example, a so-called 'back-stop' technology. It might be modified, however, in the presence of new information. If there were a back-stop technology to cap the costs of emissions reduction, introducing price caps would obviously be less useful.

Finally, because climate change is driven not by emissions themselves but by their slow accumulation in the atmosphere, price-driven variations in decadal emissions, which can be on the high or the low side, tend to cancel out. The additional uncertainty introduced with concentration is small compared with the uncertainty of the Earth's climate sensitivity, and making the target slightly more ambitious may allow, as we will see now, in probabilistic terms obtaining similar or even slightly better climate results for much lower expected costs.

4.4. More ambitious target with price cap and price floors

We now try to achieve the same environmental results as with rigid targets. For example, we choose to reduce emissions by half from 1990 levels by 2050, as suggested by the European Union, while keeping the price cap and price floor at the same levels as in the previous case. The assumption here is that controlling the marginal costs is what matters, as this is how the public at large will perceive the maximum cost incurred, because it can easily be translated into costs per barrel of oil, litre or gallon of gasoline, or electrical kWh – in the latter case depending on the mix and efficiency of the power generation. For example, US$80 per tonne of CO_2 translates into about US$0.19 per litre of gasoline, and about US$0.056 per kWh in the USA, or US$0.04 (€0.028 as at 1 July 2009) in the EU. Hence we first consider tightening the target while keeping price caps and floors at the same levels.

The total expected costs increase to US$2,553 as the target gets more ambitious, but they remain lower than with the unmodified target and the high price caps but no price floor, and of course much lower than with the unmodified target and no price cap at all. The concentration reached by 2100 extends from 443 to 525 ppm, with a mean value of 482 ppm. In terms of temperature change, the results, as shown in Figure 15, are slightly better than those obtained with the rigid targets that led to a concentration of 484 ppm (as shown in Figures 2–4). Achieving a given concentration level exactly or on average does not make any real difference in the environmental outcome. The uncertainty introduced by price caps in concentration levels is entirely masked behind the uncertainty on climate sensitivity.

These results confirm those of earlier, qualitative analyses. Uncertain emission outcomes over a decade due to price caps create less uncertainty on concentration levels, while GHGs slowly accumulate in the atmosphere. Further, this uncertainty on concentration levels is essentially unnoticeable in the final analysis in terms of temperature change – whether one considers median values or the risk of exceeding specific values. Uncertainty on equilibrium temperature change by far dominates uncertainty on concentration levels.

Another possibility is to increase the price cap and floor levels after the target has been made more ambitious to better fit the new marginal abatement cost schedule. This allows for finding more climate-friendly combinations of caps and floors with the same target of halving global energy-related CO_2 emissions by 2050 from 1990 levels.

4.5. Symmetric safety valve and quasi-carbon tax

Here price caps are set at 150% of the best-guess MAC, and price floors are symmetrically set at 50% of the best-guess MAC.[2] The total expected costs of that policy would be US$4,638 billion,

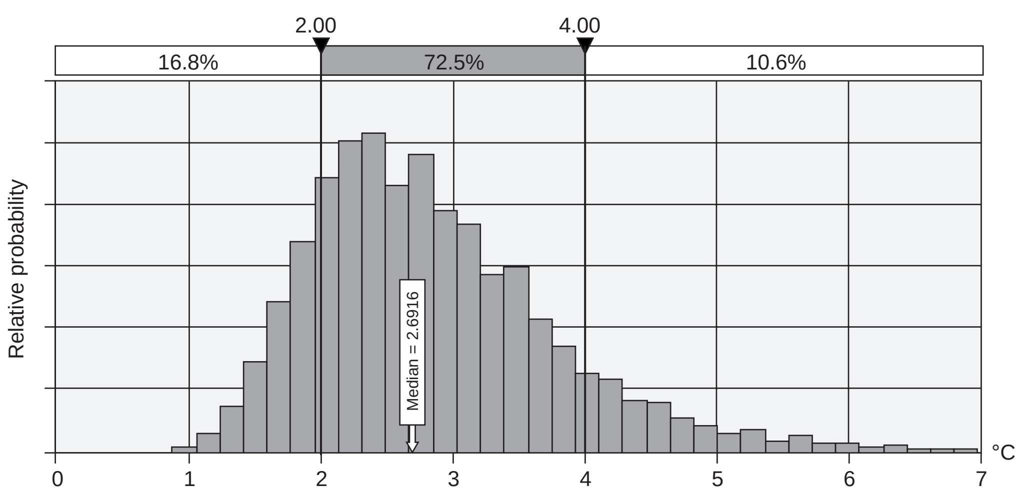

FIGURE 15 Warming committed by 2100 with a target of half 1990 levels, price caps and floors

which is significantly higher than in the previous cases, though still lower than with rigid targets. The concentration by 2100 would range from 444 to 517 ppm, with a mean value of 476 ppm. The temperature change committed by 2100 would have a median value of 2.63°C – an improvement over all previous attempts.

The ACTC model also allows for modelling a carbon tax, or a quasi-carbon tax. The 'managed-price approach' proposed by the Congressional Budget Office in the USA (Elmendorf, 2009) could probably also be analysed in the same way. It suffices to set price caps and price floors at almost the same levels. Running it with the more ambitious target (halving emissions by 2050 from 1990 levels) and price caps and floors set with US$1 difference above and below the best-guess marginal costs resulting from this target[3] yields interesting results.

Of course, there would be many differences between a large price corridor and a very narrow one, as illustrated by the two cases offered here. In the first case trading would occur, while in the second there would be very little trading, if any. An assessment of these differences is beyond the scope of this article. But it is interesting to test the carbon tax or similar instruments using the same methodology.

A quasi-carbon tax would reduce total abatement costs by comparison with the previous case, as they would reach US$4,212 billion. A considerable dispersion in emission possibilities in each decade before 2050 leads to the greatest dispersion of concentration outcomes, from 424 to 530 ppm by 2100, with a mean value of 475 ppm. The results (shown in Figure 16) are even slightly better than with the symmetric safety valve, with a committed temperature change of 2.62°C (median value) by 2100.

4.6. Still more ambitious targets, price caps and price floors

We now attempt to find a combination of targets that would entail the same expected costs as rigid targets – and presumably deliver better environmental results.

One combination that goes a long way in that direction consists in setting the 2050 target at a quarter of 1990 levels, or 52.6 Gt CO_2 in 10 years. Optimal intermediate targets are computed to minimize the net present value of abatement costs to 2050 using best-guess values.

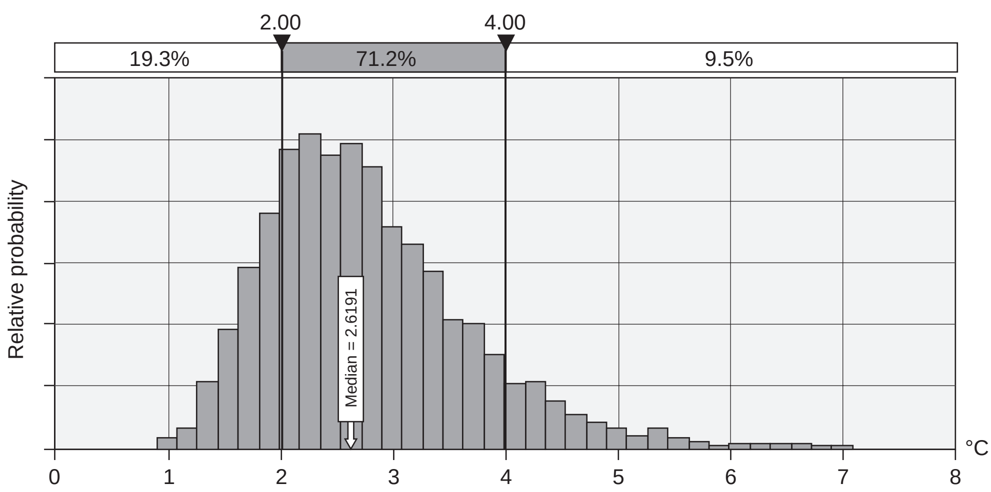

FIGURE 16 Warming committed by 2100 with a quasi-tax

Price caps are set at US$150, 240, 360 and 600, which are slightly above the best-guess MAC resulting from that ambitious objective. Price floors are set at US$50, 80, 120 and 200 for the periods 2011–2020, 2021–2030, 2031–2040 and 2041–2050, respectively.

Emissions end up on average at 88 Gt CO_2 in the period 2041–2050, or 43% of 1990 levels (30% of 2005 levels), as shown in Figure 17. The ambitious target is reached in about 40% of the cases. There is a 17% chance that the original, rigid target of half 2005 levels is exceeded.

The net present value of expected abatement costs to 2050 is US$6,762 billion – still lower than halving emissions from 2005 levels with certainty. Concentrations by 2100 end up in the range 440–498 ppm, with a mean value of 462 ppm. The resulting temperature change committed by 2100 shows a median value of 2.49°C; the chance of not exceeding 2°C is 24.1%, the risk of exceeding 4°C is 7.3% (Figure 18).

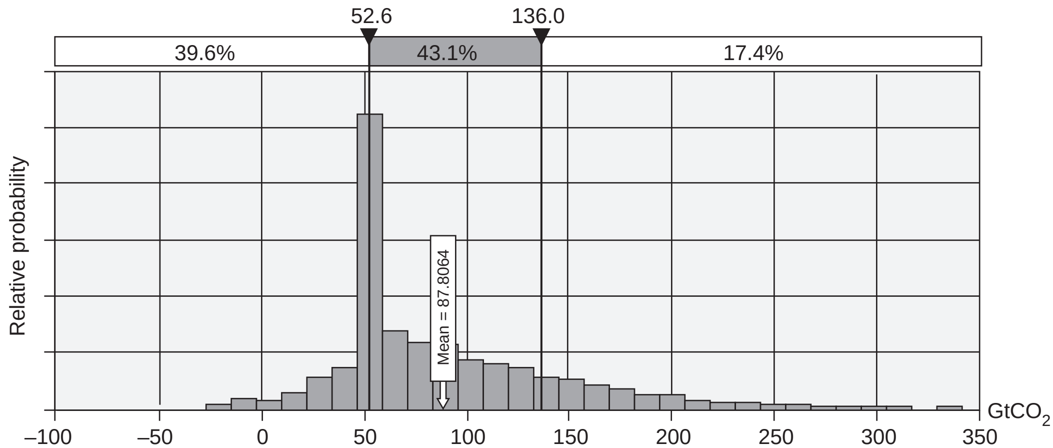

FIGURE 17 Actual emissions 2041–2050 with target 25% of 1990 levels, price caps and floors

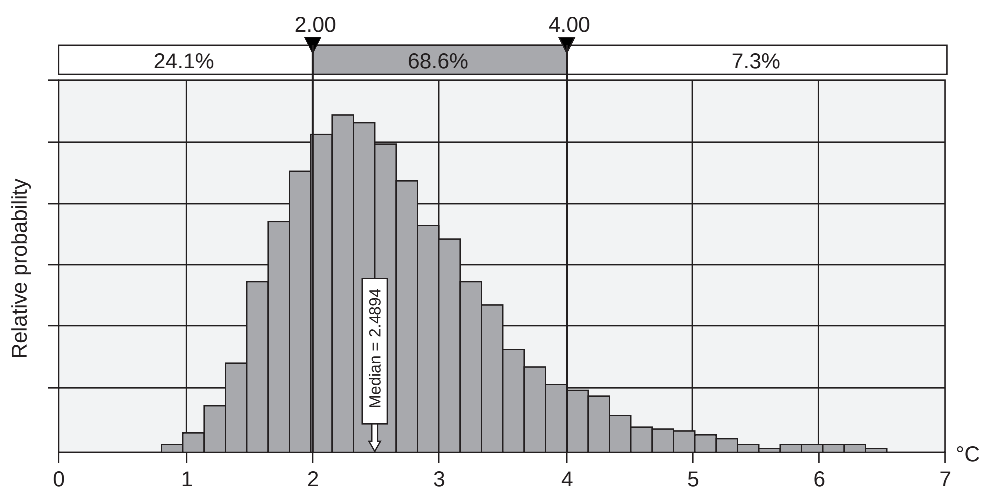

FIGURE 18 Warming committed by 2100 with target 25% of 1990 levels, price caps and floors

4.7. Allowance reserve

Finally, the ACTC model was modified to simulate an allowance reserve, as suggested by Murray et al. (2009). The additional allowances in the reserve would be put on the market if the carbon price reaches some trigger level; however, if the reserve is exhausted, the price is no longer limited. The system behaves like a 'limited' price cap system. In the framework of targets set to halve global energy-related CO_2 emissions by 2050 from 2005 levels, with price caps and price floors similar to those described at the beginning of this section, an allowance reserve set at 10% of total amount of allowances for a given period was tested; Figure 19 shows its effects on the distribution of emission outcomes.

A growing reserve, from 10% to 25% of allowed emissions, was also tested. The results are shown in Table 3 and compared with those obtained with a more ambitious policy (halving global emissions from 1990 levels) and plain price caps. This shows that more ambitious policies with unlimited price caps and price floors might be preferable to schemes with price caps limited in size due to an allowance reserve.

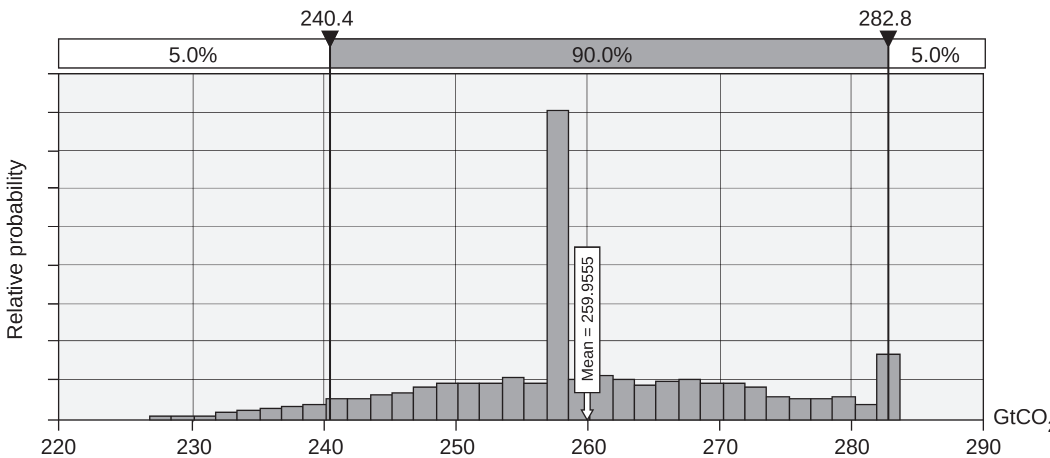

FIGURE 19 Emissions 2011–2020 with a 10% allowance reserve

TABLE 3 Allowance reserve vs. (unlimited) price caps

Policy	Price caps *Price floors*	Discounted abatement costs to 2050 (mean)	Warming committed by 2100 (median)
Rigid targets	None *None*	$7,885 billion	2.72°C
10% allowance reserve	$80–260 *$40–130*	$6,282 billion	2.71°C
Growing reserve (10–25%)	$80–260 *$40–130*	$5,122 billion	2.72°C
Tighter targets Unlimited price caps	$80–260 *$40–130*	$2,553 billion	2.69°C

5. Discussion and conclusions

A number of observations can be made from these results, summarized in Table 4. The first is that mitigation action, whatever its form and costs, makes an enormous difference in the resulting climate change by the end of this century.

The second is that, given the spread of the uncertainties relative to unabated emission trends and abatement costs, price caps can significantly reduce cost uncertainty and expected costs – by up to two-thirds, according to the assumptions of the model. Meanwhile, price floors help to maintain the environmental effectiveness of the policy. Price floors increase the costs attached to some targets, but contribute to keeping the costs low in achieving a given environmental result.

Price-driven variations in emissions have little influence on policy outcomes (temperature change), if price cap and price floor levels are roughly consistent with the ambition of the policy. As previously pointed out by Pizer (2002) and Newell and Pizer (2003), this is primarily explained by the stock nature of the issue of climate change: the slow build-up of CO_2 concentrations smoothes short-term emission changes. Our results further point to the role of uncertainty on the Earth's climate sensitivity, which by far exceeds and in some ways masks the uncertainty on emission levels.

Tighter targets with price caps and price floors entail lesser economic risks and similar or slightly better climate results. For example, halving emissions by 2050 from 1990 levels with price caps and floors offers similar environmental results as halving emissions from 2005 levels with straight targets – but for one-third of the (expected) costs, according to the assumptions of the model. Alternatively, a significantly more ambitious target could be chosen, with better climatic results, with expected costs still lower than those implied by a rigid but less ambitious target.

TABLE 4 Summary of results

Policy	Target 2050 *Price caps* Price floors (2011 to 2050)	Abatement costs 2011–2050 (npv) *Min-Av.-Max in % WGP*	Warming committed by 2100			
			ppm	°C	<2°c	<4°C
Half 2005 level	**13.6 Gt CO_2** No price cap	\$ 7 885 bn *0–0.4–5.5*	***479*** ***484***	**2.71**	*15.8*	*88.8*
Half 2005 + price caps & floors	**13.6 Gt CO_2** *\$ 80 to \$ 260* \$ 40 to \$ 130	\$ 2 292 bn *0–0.12–0.19*	***441*** ***528***	**2.75**	*15.3*	*88.1*
Half 1990 + caps & floors	**10.5 Gt CO_2** *\$ 80 to \$ 260* \$ 40 to \$ 130	\$ 2 553 bn *0–0.13–0.2*	***443*** ***525***	**2.69**	*16.8*	*89.4*
Half 1990 + caps & floors	**10.5 Gt CO_2** *\$ 132 to \$ 511* \$ 44 to \$ 170	\$ 4 638 bn *0–0.24–0.4*	***444*** ***517***	**2.63**	*18.5*	*90.5*
Quasi tax (half 1990)	**10.5 Gt CO_2** *\$ 88 to \$ 342* \$ 87 to \$ 341	\$ 4 212 bn *0–0.2–0.3*	***423*** ***530***	**2.62**	*19.3*	*90.5*
Tighter target + caps & floors	**5.26 Gt CO_2** *\$ 150 to \$ 600* \$ 50 to \$ 200	\$ 6 762 bn *0–0.35–0.5*	***440*** ***498***	**2.49**	*23.7*	*92.9*

With respect to economic risks, taxes are similar to permits with price corridors, and both dominate straight targets. In a recent defence of emissions trading, Nathaniel Keohane (2009) notes, however, that taxes may focus the public debate on the cost of abatement, while quantitative targets may focus it on the ‘cap’ or the environmental necessity of addressing the threat of climate change. Hopefully price caps could be less prone to such a psychological effect, as they would be part of hybrid instruments together with emission targets and price floors (which may help avoid a cap on the marginal abatement cost being mistaken for a cost).

In these results, the reduction of expected costs can only partly result from so-called time flexibility. Banking and borrowing, for example, could reduce expected costs if the volatility of carbon prices is due to successive economic shocks of opposite signs. If, however, BaU emissions over time show a progressive departure from expectations, being constantly above or below expected trend, time flexibility will do little or nothing to reduce costs, if at the end of the day all deviations from targets must be corrected and the ‘integrity’ of the targets must be restored (see Fell et al., 2008).

In running the ACTC model with price caps and floors, the reduction in expected costs results primarily from the flexibility given to adjusting the emission levels to the actual abatement costs. This is also what makes it difficult to accept by many. However, this is a logical consequence of accepting that abatement costs are considered in defining the level of abatement. If only benefits were considered, the optimal emission level would be the lowest one – for the sake of the climate it would be better to halt GHG emissions right away. But this is usually not considered possible, for the costs would be too important.

However, if abatement costs are considered in setting the objective, then it is legitimate to adjust the level of abatement to those costs. Uncertainties prevent performing *ex ante* a full cost–benefit analysis. To some extent the difficulties in assessing the monetary value of the damage associated with climate change are likely to persist. Nevertheless, as abatement costs are considered in setting quantitative emissions targets, it seems legitimate to adjust them if these costs deviate from expectations. This is what price caps and floors do, in a manner that remains predictable by investors and does not undermine the confidence that market players may have in the stability of climate change mitigation policies.

In conclusion, short-term certainty on emissions appears less important than long-term policy ambition. The usual criticism is that marginal damage from climate change may be highly non-linear and grow very rapidly beyond some thresholds. This would justify the choice of a policy delivering guaranteed results, such as straight targets of firm caps on emissions. However, Pizer (2003) showed that there would be a preference for straight targets only if the thresholds themselves – for example GHG concentration thresholds – were known with full certainty. If this is not the case, the most ambitious policy remains preferable.

This appears all the more true if, as is likely, the non-linear damage would be triggered by temperature change. Price caps and floors seem appropriate in order to help governments accept slightly more ambitious policies. Given the uncertainty on the Earth’s climate sensitivity, these policies may have slightly better expected results than the policies with more ‘certain’ results due to straight targets. Despite the flexibility allowed in emission levels, the ‘more ambitious, less certain’ policies are, in practice, less likely to meet the unknown temperature change level that would trigger these most-feared non-linear damages.

This quantitative assessment, however, does not provide all the answers. It is limited to carbon dioxide emissions from fossil fuel combustion. It does not address the effects of limiting price volatility on investors’ behaviour. Nor does it address complex implementation issues related to linking a global, international regime with domestic, nation-wide emissions trading schemes, or linking these schemes altogether, when price caps and price floors are involved. These issues require further work.

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Notes

1. There is a small probability that BaU emissions, close to the end of the century, could fall below target emissions, as a result of the emission reductions undertaken in the early decades of the century but which, because of how the model is constructed, permanently modify the BaU emission trajectory.
2. The price caps would be set at US$132 per tonne CO_2 in 2011–2020; US$202 in 2021–2030; US$318 in 2031–2040; and US$511 in 2041–2050. Price floors would be set at US$44 in 2011–2020; US$67 in 2021–2030; US$106 in 2031–2040; and US$170 in 2041–2050.
3. In this case, price caps and floors would respectively be set at US$88 and 87 in 2011–2020; US$135 and 134 in 2021–2030; US$213 and 212 in 2031–2040; and US$342 and 341 in 2041–2050.

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